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M.V. ARCTIC
Manoeuvering Performance

Summary Report

Prepared for

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Manoeuvring Performance in Ice
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TP 5683E

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DISCLAIMER

The contents of this report reflect the views of the authors and not necessarily the official views or policies of the Transportation Development Centre.

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17. Abstract

This report describes the analysis of the manoeuvring and control characteristics of the M.V.ARCTIC in ice. The analysis is based on records accumulated over the period 1979-81, when the ship was equipped with a computerized data acquisition system that operated during both normal voyages and a series of dedicated ice trials.

The limited data base restricted the scope of the analysis. It was, however, possible to demonstrate a linear dependency of turning radius with ice thickness, and to estimate the importance of the icebreaking component of turning resistance for this ship. Other results show that ice impacts from ice passing through the propeller can give significant rudder torques, that controllability of the ship is influenced by ice type and thickness, and that,in certain situations, the bubbler system can considerably improve manoeuvring performance.

Results of the study are used to evaluate existing design regulations, noting areas where these should be amended. The instrumentation and data acquisition program are also discussed, and suggestions made for improvements in future projects.

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17. Résumé

Ce rapport traite des caractéristiques du cargo brise-glace Arctic sur les plans de la manoeuvre et du comportement dans les glaces. L'analyse porte sur les données accumulées entre 1979 et 1981 grâce au système d'enregistrement automatique à bord, lequel a fonctionné aussi bien durant les périples réguliers que durant des essais spécialisés en eaux chargées de glaces

La base des données étant restreinte, la portée de l'analyse a été limitée. Néanmoins, il a été possible de prouver la relation linéaire entre rayon de giration et épaisseur des glaces et, aussi, de déterminer la part attribuable a l'action de briser les glaces dans la résistance globale à la giration du navire. Parmi les autres résultats constatés, notons les importants moments de torsion au niveau du gouvernail causés par les glaces expulsées par l'hélice, la relation entre la manoeuvrabilité du navire et le type et l'épaisseur des glaces rencontrées et la plus grande efficacité des manoeuvres, obtenue dans certaines conditions grâce au système à bulles d'air.

Ces résultats serviront à évaluer les normes de conception en vigueur et à mettre en lumière les changements devant être apportés. Le rapport traite également de l'instrumentation et du programme de saisie de données, pour lesquels il suggère des améliorations.

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1.0 INTRODUCTION

This study was one of a number undertaken to analyse and interpret various aspects of the data gathered aboard the M.V. ARCTIC during three years of operations, 1979 to 1981. The ship was designed to operate as an ice-capable general cargo carrier in accordance with the requirements for Ice Class 2 of the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR). Throughout the period in question she was fitted with an extensive array of sensors feeding a computerized data acquisition system. This operated both during commerical voyages and in a series of dedicated ice trials, producing a total of 163 magnetic tapes.

The Manoeuvring Performance study was intended to provide information on a variety of aspects of manoeuvrability in ice, including directional stability, turning performance, steering gear performance and strength (particularly in the context of CASPPR) and also to address areas such as the value to the ship of its installed bubbler system in manoeuvring situations. Relatively few of these subjects have hitherto received much theoretical or experimental attention, making any results from this study of considerable interest. The extent and quality of the data available limited the analysis which proved possible, as discussed below. However, a number of useful findings did result, and are summarized in this report.

2.0 DATA EXTRACTION AND VALIDATION

After studying the M.V. ARCTIC Master Data Package (which summarizes operating conditions and sensor status for each tape) a selection was made of the sensors and tapes containing information considered relevant to the project objectives. The tapes chosen concentrated on the trials in the Saguenay River (1980), off Baffin Island (1980), and in Lake Melville (1981) with other voyage monitoring tapes chosen to fill some gaps in the data base. Information was also drawn from various earlier reports, ship log books, etc..

The sensors selected for investigation were:

2.0 DATA EXTRACTION AND VALIDATION (Cont'd)

- Sway forward	(Channel 2)	
- Rudder stock strain	(Channel 196)**	✓
- Thrust	(Channel 198)	✓
- Rudder angle response	(Channel 200)	✓
- Differential rudder pressure	(Channel 202)	
- Shaft torque	(Channel 208)	✓
- Shaft RPM	(Channel 209)* (Channel 211)**	✓
- Sway Aft	(Channel 213)	
- Sway aft, filtered	(Channel 216)*	
- Wind speed	(Channel 233)	✓
- Wind direction	(Channel 234)	✓
- Ship's speed	(Channel 236)	✓
- Ship's heading, cosine	(Channel 237)	✓
- Ship's heading, sine	(Channel 238)	✓
- Pitch angle	(Channel 239)**	
- Roll angle	(Channel 240)	
- Rudder command	(Channel 245)	✓

N.B. * - 1979 to 1980 Seasons only

** - 1981 Season only

✓ - Channels yielding good quality information

As indicated, not all were operational during any recording period.

Data retrieval and reduction from the tapes was performed on a main-frame computer, using user-defined start and stop times to avoid problems known to exist with header and end blocks. The data was then transferred to an H.P. 9826 desktop computer, and stored on floppy discs. Software developed for this machine was used to produce plots in engineering units for the selected signals, and later to process this basic data into forms more appropriate to particular investigations.

The data was validated by comparing the signals with manually recorded data where this exists; by examining the form of the signal alone and in relation to simultaneously recorded signals from either samples; and by direct calculation to produce expected values in given situations. It

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was found that some sensors never produced useful signals, either through being non-operational or improperly calibrated, or else due to system noise or signal drift. Those sensors indicated above are felt to have produced fairly reliable information most of the time, though individual samples can be somewhat dubious, and certain sensors (e.g. the doppler speed log) are not particularly accurate.

3.0 EXTENT OF AVAILABLE DATABASE

Problems with sensors limited the comprehensiveness of the information gathered in any situation, but larger handicaps to the analysis were the relatively small number of recordings made in circumstances relevant to manoeuvring, and the procedures followed in the dedicated trials. These produced a small population of results, over which few parameters were varied in a systematic fashion. The range of operational categories which could be investigated was therefore restricted to:

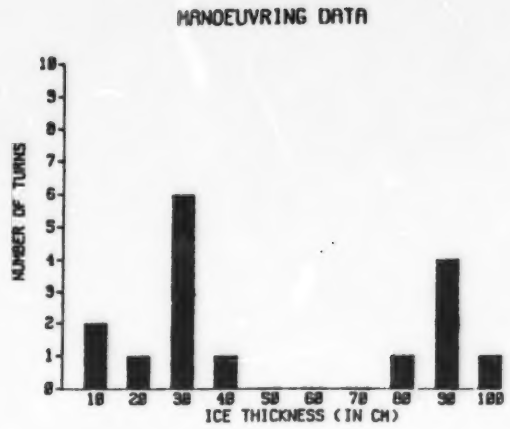
Open Water Operations:	Continuous ahead motion
	Course alterations
Homogeneous Ice Operations:	Continuous ahead motion
	Course alterations
	Astern motion

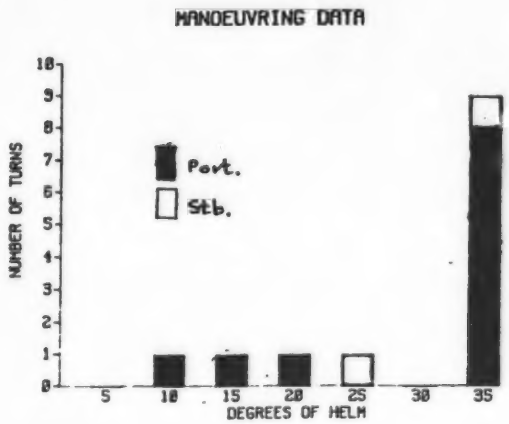
During the manoeuvring trials the range of ice thicknesses, rudder angles, and shaft powers covered is shown by FIG. 3.0. The sparse coverage in many areas is apparent. More records are available for continuous ahead motion, and have been used in some areas of analysis. Their interpretation however tends to rely on assumptions as to the operators intent at the time of the recording.

4.0 MANOEUVRING PERFORMANCE ANALYSIS

4.1 Turning Performance

A turn in ice consists of an initial transient phase, during which values of speed and turning rate change; a steady phase; and, in cases where a turn is sustained a third phase in which the approach towards


MANOEUVRING DATA
NUMBER OF TURNS
ICE THICKNESS (IN CM)


MANOEUVRING DATA
NUMBER OF TURNS
Port.
Stb.
DEGREES OF HELM

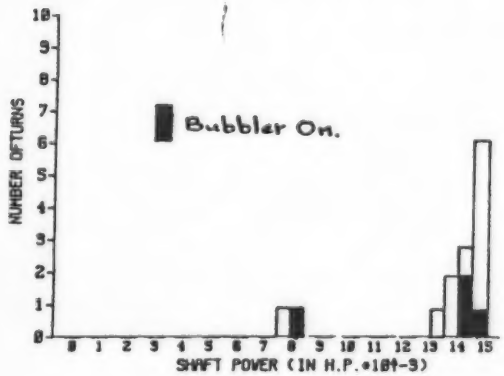

MANOEUVRING DATA
NUMBER OFTURNS
Bubbler On.
SHAFT POWER (IN H.P.*10**-3)

FIGURE 3.0

the previously broken track allows speed and rate of turn to increase, see FIG. 4.1-1. At no time is turning in ice smooth and continuous. The ice sheet fails in a succession of discrete events which are reflected in the motions of the ship. There are thus several basic differences between turning in ice and in open water.

The transient phase becomes shorter as ice thickness increases. This is easily explained by lower initial speed and kinetic energy of the ship, which combined with larger resistance forces will lead to a new equilibrium condition more rapidly than in open water.

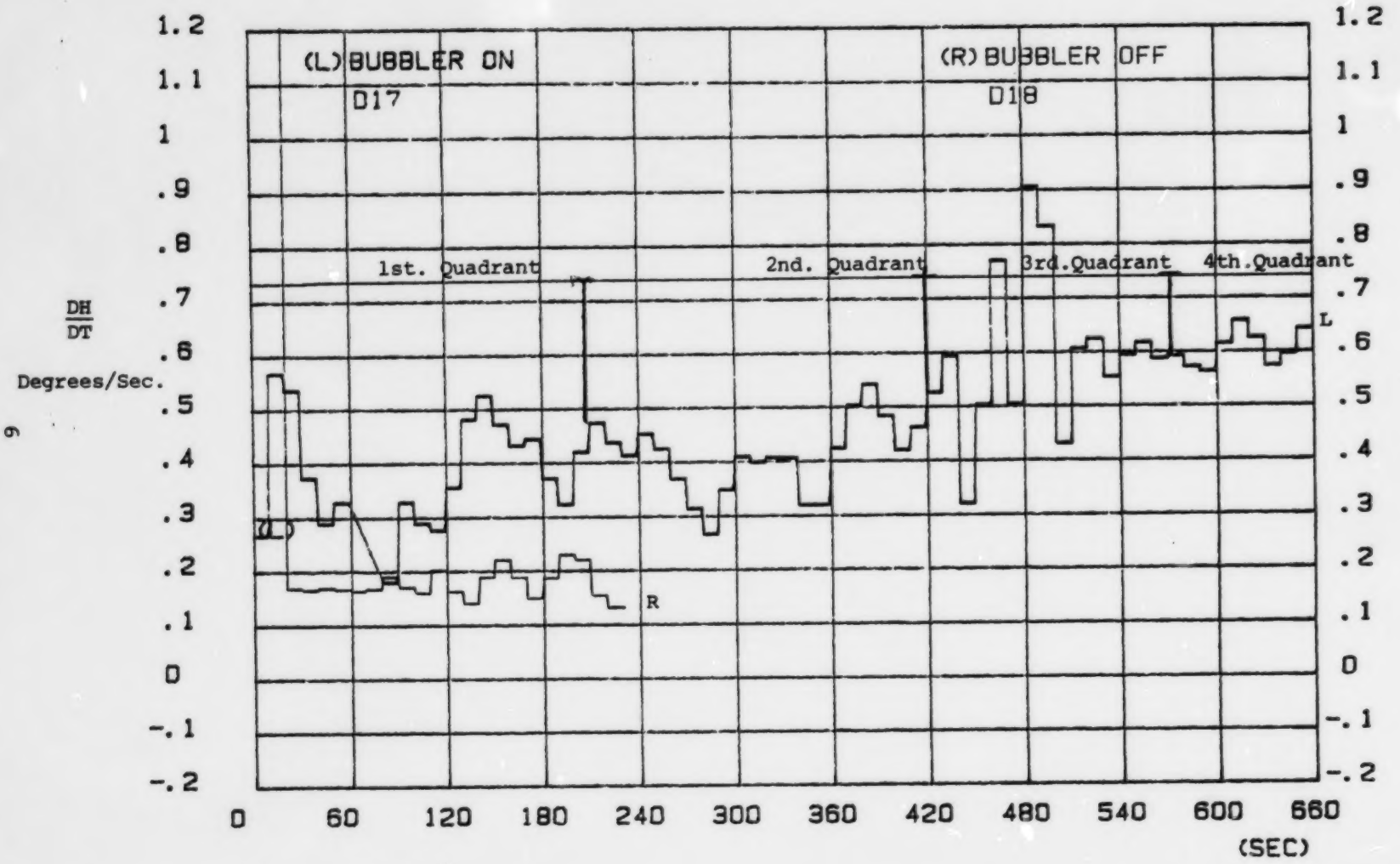
The turning rate in the steady phase, the advance in a 90° turn, and the advance and transfer involved in a course reversal (180° turn) are all quantities of importance to the operator, who will also wish to know the extent to which he can control them in a given situation. FIG. 4.1-2 presents a set of points of turning radius (non-dimensionalized to R/L, L ship length) plotted against ice thickness, from which certain hypothesis have been drawn. The vertical line through each mean point indicates the magnitude of the scatter in the turning rate results.

A set of otherwise comparable turns were performed in varying ice thicknesses at Baffin Island and in the Saguenay River. These have yielded the linear trend line for increasing turning radius with increasing ice thickness. The speed drop with increasing ice thickness means that the time for a given manoeuvre increases as roughly the square of thickness.

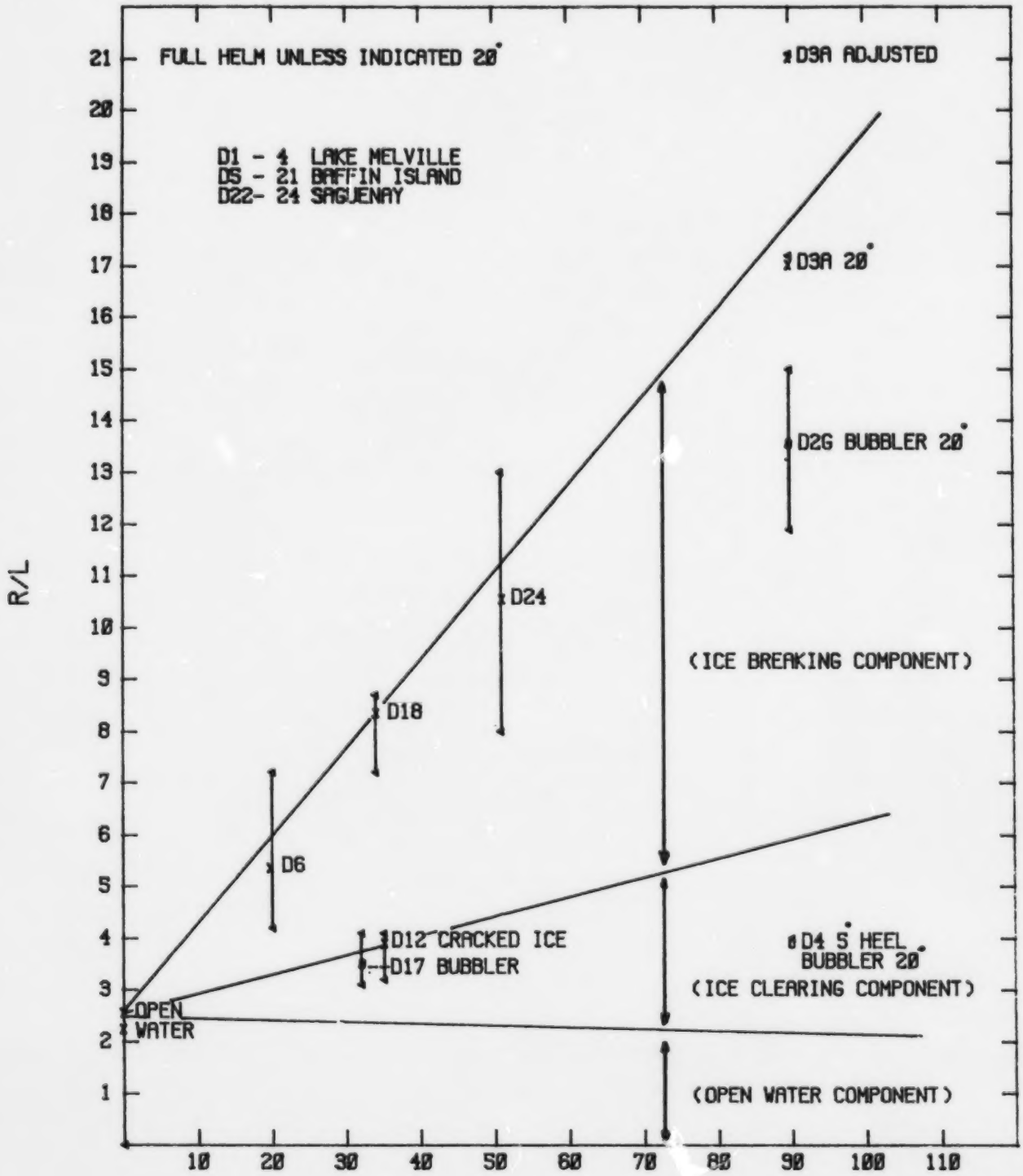
The importance of the breaking component in the total turning resistance has been deduced tentatively from a few results, amongst which is D12 for a turn in cracked and broken ice. The remaining 25% of resistance will result from submerging and otherwise displacing the broken fragments.

Trials in weaker ice were performed in Lake Melville. It has been assumed that the breaking component of resistance is linearly proportional to flexural strength, on which basis Lake Melville results have been

FIGURE 4.1.1



Unsteadiness in turn,
Also showing 3rd. and 4th. Quadrant Effect
And Influence of Bubbler



STEADY TURN RADIUS UNDER VARIOUS CONDITIONS

FIGURE 4.1.2

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replotted. It is felt that the closeness of the 20° helm spots from the Lake Melville to the 35° helm results from elsewhere may indicate the existence of a critical rate of turn in ice, beyond which resistance to a higher turning rate rises more rapidly than does the turning moment from increasing rudder angle.

If the ship is heeled in the direction of turn, it presents a more efficient icebreaking shape at the extremities of the midbody where breaking occurs. The effects are shown in the point D4, for which a very sharp turn resulted.

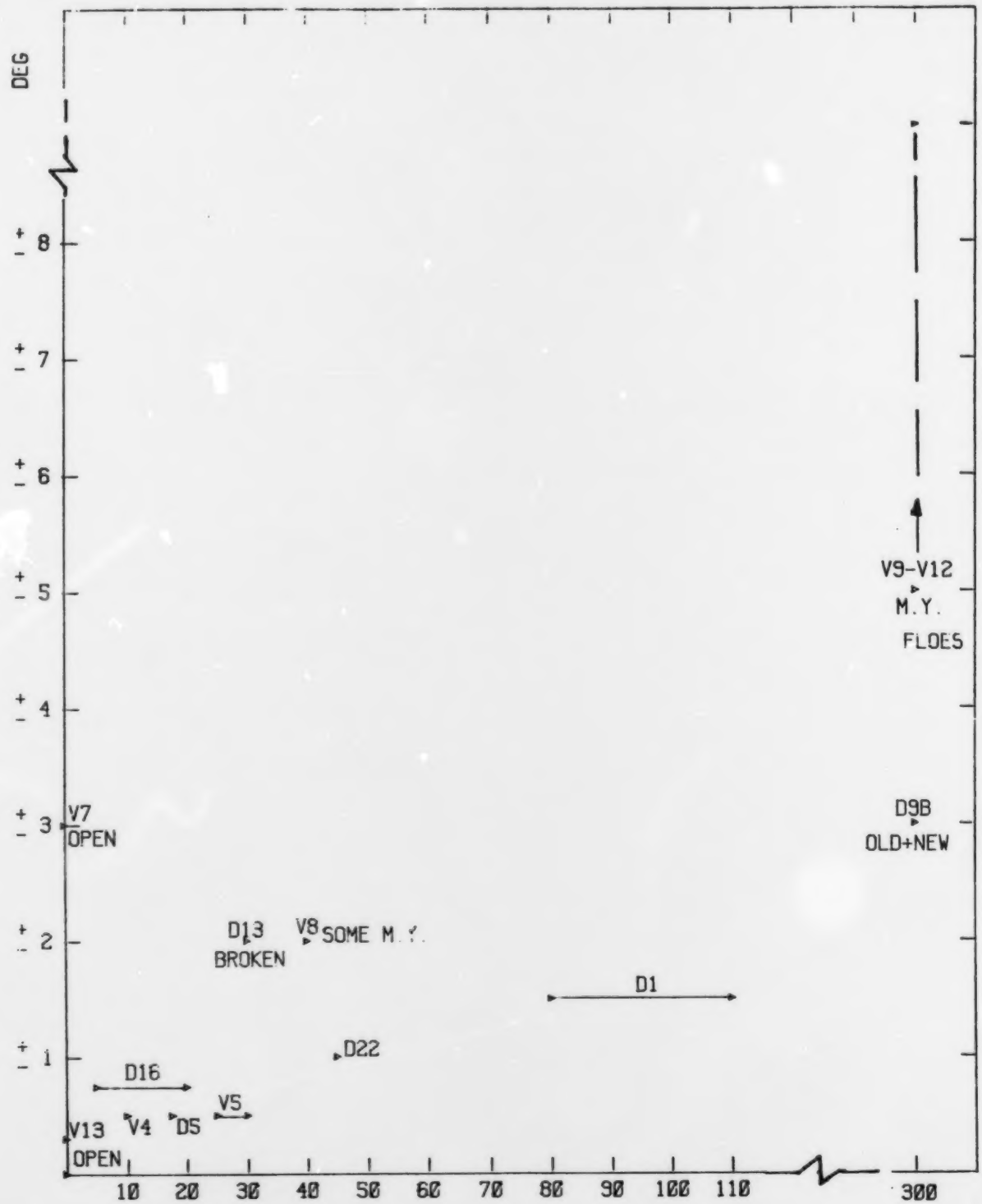
4.2 Ice Impacts with Steering

The few records available describe rudder stock torques during ice impacts. In varied ice conditions these reached values calculated to be 160 - 170% of the maxima expected in open water. It is difficult to be certain, but indications from other channels such as propeller thrust and torque indicate that the impacts recorded resulted from ice passing through the propeller.

4.3 Directional Stability

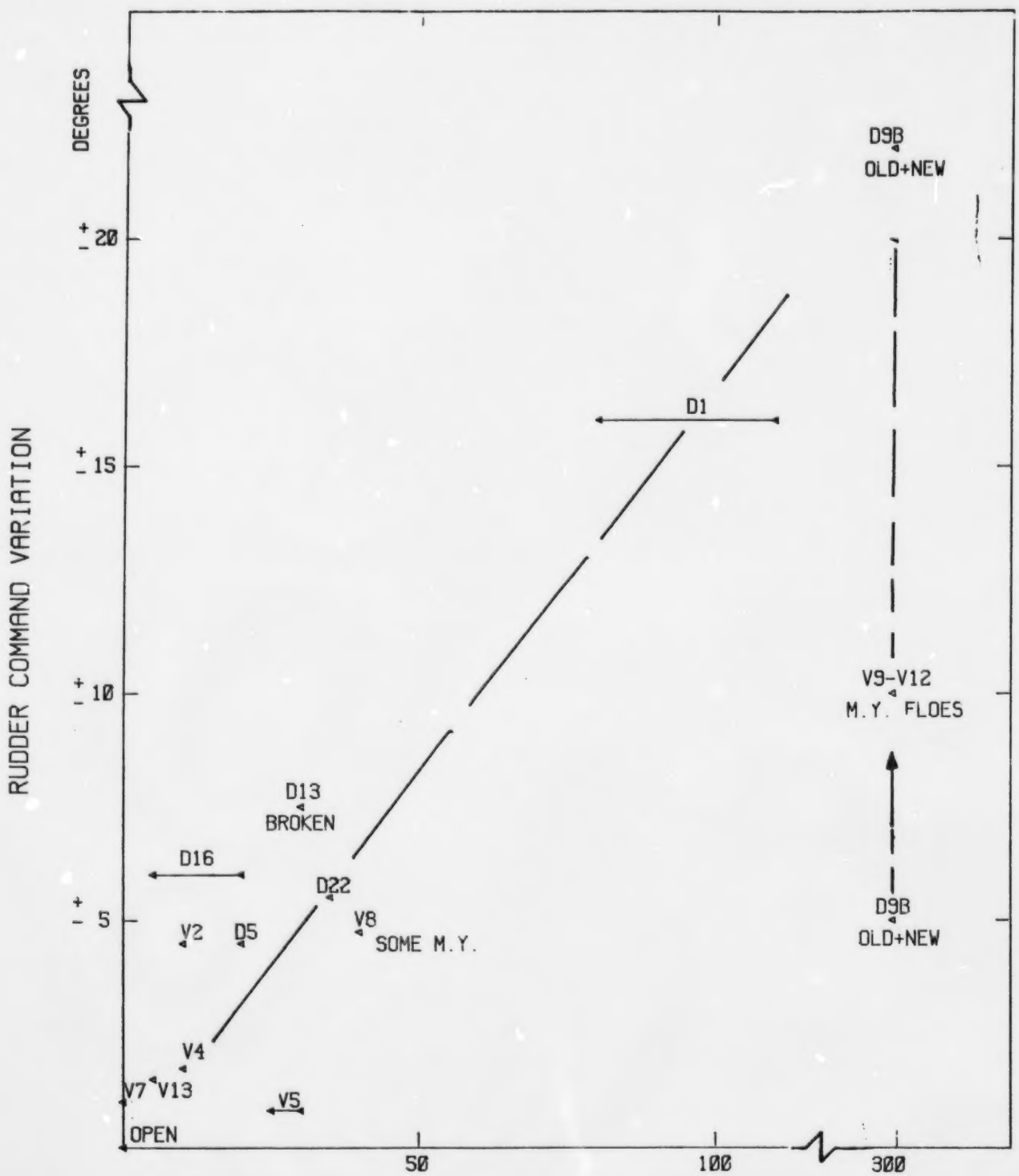
Calculations show that the M.V. ARCTIC is controls-fixed directionally stable in open water. No theoretical method presently exists to perform similar calculations for the case in ice. The inhomogeneities of the material lead to frequent small perturbations which for a directionally stable ship would be expected to be self-cancelling in the long term. In practice however the operator tends to react to these as they occur, making the underlying ship control characteristics difficult to determine.

FIG. 4.3-1 shows that the range of perturbations, expressed as heading variations tends to increase in thicker and more inhomogeneous ice. This leads to larger helm angles being used during ahead motion in ice than in open water (FIG. 4.3-2). The range of rudder angle



RANGE OF HEADING VARIATION WITH ICE THICKNESS

FIGURE 4.3.1



RANGE OF RUDDER COMMANDS USED DURING AHEAD MOTION WITH ICE THICKNESS

FIGURE 4.3.2

4.3 Directional Stability (Cont'd)

commanded to recover from a heading perturbation of a given size also seems to increase with ice thickness, presumably because the response of the ship is slower under such conditions.

In general however, there appears to be no problem in maintaining course within ± 2° of the desired heading in any thickness of ice. Even strong winds have little influence on the ship while transitting ice, being relatively small contributors to the overall force balance in these conditions.

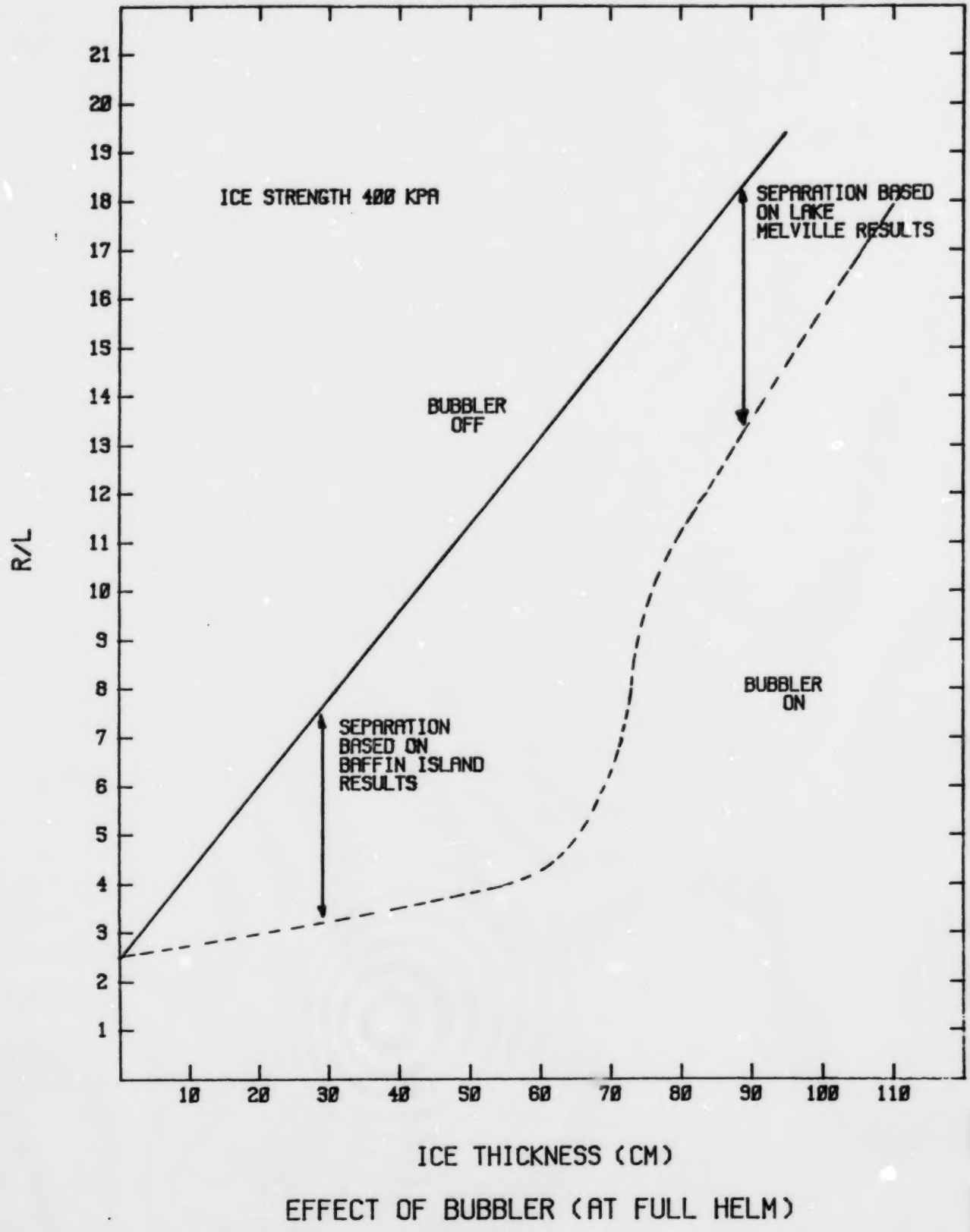
4.4 Steering Gear Response Characteristics

At a given power level, the steering gear speed of response does not appear to be strongly dependent on ice thickness. This is to be expected, as the forces resisting response result from the water velocity over the rudder, which for the configuration chosen for the M.V. ARCTIC does not vary much at a given power level.

4.5 Influence of Bubbler System

As can be seen from both FIGS. 4.1-1 and 4.1-2, the bubbler can considerably increase the rate of turn in ice of certain thicknesses, and offers certain benefits in thicker ice as shown in FIG. 4.5. At its most effective, it is assumed to contribute largely to breaking the ice by removing its buoyancy, while in more severe conditions it will be more limited to lubricating and clearing away previously broken fragments.

Unlike a conventional thruster the bubbler is therefore operating by reducing turning resistance rather than increasing turning moment, and at its best achieves a performance enhancement much greater (up to 60% reduction in turning radius) than any practical thruster could provide. The thrust required to produce this improvement has been calculated as approximately 200 tonnes force.



EFFECT OF BUBBLER (AT FULL HELM)

FIGURE 4.5

5.0 EVALUATION OF CASPPR PROVISIONS FOR MANOEUVRING IN ICE

No previous or existing version of the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR) has attempted to ensure adequate manoeuvrability for ships in ice. Until more knowledge is amassed about ship characteristics influencing manoeuvrability it will be impossible to assess the performance of a given design accurately, but it can be said that major factors are installed power, and rudder position and size. The turning moment available from a rudder depends largely on the flow over it, which will be enhanced by placing the rudder behind a powerful propeller race. This may not be necessary for all ships, but it is felt that the appropriate turning force for any design should be a factor in the approval process.

Present rudder stock strength requirements of CASSPR are vague, but based on ice impacts for the M.V. ARCTIC earlier specific standards were inadequate. It is possible that for some ships the worst design case should consider impacts with large fragments or an infinite ice sheet during rapid turns, but as a minimum all designs should resist the impact of a piece of ice ejected by the propeller when this can hit the rudder. Size and speed of such a piece can be readily calculated. This form of impact is also likely to be the worst case for local plating design. Motion astern can undoubtedly operate very large loads on the rudder, but this is best guarded against by a combination of fitting protection such as ice horns and ensuring sound ship-handling.

Steering gear response speed is specified by classification societies and by CASPPR. It is considered that the open water requirements of the former do not need to be supplemented by the latter for operations in ice, as the system response speed is not affected by the presence of ice and the slower ship response makes a faster system response unnecessary. CASPPR should cover instead such areas as redundancy of mechanical components.

6.0 EVALUATION OF DATA ACQUISITION PROGRAM AND WAY AHEAD

Further research and experimentation is needed to fill the gaps in the existing database and to follow up the findings to-date. Full scale tests should apply the lessons learnt from this project in areas of instrumentation design and acquisition strategy. The instrumentation fitted between 1979 and 1981 had a number of teething problems, and in some sensors used sensitivities or sampling rates which were not optimized for the quantities to be measured. Speed is a parameter both important and difficult to measure accurately from aboard the ship. It is felt that in future dedicated trials the additional effort of setting-up a distance/speed measurement system on a local fixed point would be well repaid.

Planning any tests on longer-term projects must specify the objectives and define and provide the resources and procedures necessary to achieve them. The manoeuvring performance aspects of the 1979 to 1981 program did not have a good acquisition strategy in any of these respects. If any performance characteristic is to be determined, the quantities defining it and the parameters affecting it both have to be measured, using instrumentation selected and calibrated for the purpose. Instrumentation may include ships equipment and dedicated trials instrumentation on and off the ship. The readings from all of these should be checked and cross-checked regularly, and recorded in such a way that all relevant information can be easily accessed for future analysis.

Future full-scale trials could usefully investigate turning performance dependency on power level, rudder angle, and ice strength; all areas where little information yet exists. A model testing program could also be developed to extend the scope of full-scale work, having first used existing results to validate the modelling techniques. Purely theoretical studies into the mechanisms involved in turning in ice may be able to identify more accurately their relative importance, and others could be performed to expand the scientific data base upon which regulations such as CASPPR can be updated.

7.0 CONCLUSIONS

7.1 Evaluation of Database

The records made during the M.V. ARCTIC's operations from 1979 to 1981 have been examined and the majority of the information relevant to manoeuvring performance has been extracted, validated, and reduced. This has allowed the determination of areas in which useful information is available, and equally of areas where good results are lacking.

The data of good quality is predominantly relevant to manoeuvring in homogenous ice, and to ahead motion (directional capability and control) in a somewhat wider range of conditions. Within these categories there is a very restricted coverage of the effects of various controllable and environmental parameters, due principally to the small number of manoeuvring tests performed.

More useful information could have been obtained from the tests performed if sensors had been better selected and/or set to work, and if more planning of the test activities had been performed beforehand. Future investigations of manoeuvring performance should give all these areas careful consideration.

7.2 Analysis of Results

From the information available it seems reasonable to deduce that the steady rate of turn in ice decreases linearly with increasing ice thickness, and that as a result of the speed loss in ice the time taken to achieve a given change of heading increases as roughly the square of ice thickness. A few results suggest that the bulk of the resistance to turning in ice (75%) comes from the need to break additional ice with the sides of the ship, the rest coming from the need to displace the broken ice. The icebreaking component is assumed to be proportional to the flexural strength of the ice.

The controllability of the ship in ice is affected by both the thickness and type of ice; multiyear (and therefore probably less homogeneous) ice causing greater heading perturbations than does first-year

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7.2 Analysis of Results (Cont'd)

ice, and leading to more significant actions by the helmsman to maintain course. Thicker ice is also associated with more helm activity, though this may have much to do with the slower response of the ship in such conditions.

Significant ice impacts with the rudder have been recorded under a variety of running conditions, and generally seem to be associated with ice passing through the propeller nozzle. Excluding such incidents, the presence of ice appears to have little influence on the command/response characteristics of the steering gear.

The bubbler system installed on the M.V. ARCTIC can increase the manoeuvrability of the ship very considerably over the range of conditions in which the system is capable of breaking the ice sheet. In this range it offers benefits greater than those which any practical alternative could provide.

7.3 Evaluation of CASPP Regulations

The results of the M.V. ARCTIC trials point to the need for future CASPP Regulations to ensure that the combination of installed power and rudder configuration are adequate to produce sizeable turning moments at low speeds. Requirements should take account of the likely resistance to turning of particular hull forms.

Present CASPPR should be amended to provide more useful design guidance on the strength of components such as the rudder stock. It is considered that the original CASPPR criteria were inadequate to ensure rudder stock integrity, and that new standards should require roughly 100% greater strength.

Steering gear rate of response is regarded as an inappropriate basis for design. It is felt that more emphasis should be placed on redundancy of components to provide greater safety in Arctic waters operations.